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# Back Bay, Virginia: A Literature Review and Synthesis of Natural Resource Status and Trends

Virginia Field Office
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# BACK BAY, VIRGINIA: A LITERATURE REVIEW AND SYNTHESIS OF NATURAL RESOURCE STATUS AND TRENDS

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# EXECUTIVE SUMMARY

This literature review and synthesis was undertaken by the U.S. Fish and Wildlife Service (Service) as a part of the Back Bay Initiative. The Back Bay Initiative is a compilation of efforts in response to the tremendous interest expressed by the Service and numerous public and private agencies, researchers and environmental and land use planning groups concerned about the quality of the Back Bay, Virginia watershed. This synthesis of the historic trends and current status of water quality and the natural resources in Back Bay is meant to provide interested parties with the information that is necessary to make informed decisions about the future of this important natural resource. In the last 150 years, Back Bay has undergone a general decline in water quality, as well as fluctuations in submerged aquatic vegetation (SAV), fish, and waterfowl populations. Defining the trends in water quality and natural resources required review of scientific literature, records maintained by Back Bay National Wildlife Refuge, and even reported anecdotal observations dating back to the late 1800s.

In summary, Back Bay, Virginia is changing from a marine to a slightly brackish, more freshwater environment. This is naturally occurring as the sources of saltwater, including naturally-occurring openings to the Atlantic Ocean and intentional pumping of saltwater into Back Bay, no longer exist. Abundance of submerged aquatic vegetation has undergone several long-term downward trends since the early 1900s and has not fully recovered to the former abundant conditions of the past century. There are indications that the submerged aquatic vegetation may be in a recovery period in the early 1990s. Factors contributing to the fluctuations and declines of SAV populations include increased nutrient and pollutant loads from many sources. Since the beginning of this century, there has also been a persistent decline in waterfowl populations and species diversity. Lastly, the general fish population, less abundant now than historical records indicate of past populations, is changing to a more freshwater species composition.

## ACKNOWLEDGEMENTS

The authors would like to acknowledge the many agencies, researchers, and individuals whose collective and cumulative contributions and records of Back Bay, Virginia made this document possible. This report was funded by the U.S. Fish and Wildlife Service: Project Code 90-5109, Fiscal Year '90.

## TABLE OF CONTENTS

## LIST OF FIGURES

PAGE

## LIST OF TABLES

# INTRODUCTION

Back Bay, Virginia is a vast aquatic ecosystem situated on the coastal border of Virginia and North Carolina. It has long been noted for its abundant fish and wildlife populations. Back Bay is within the city limits of Virginia Beach, Virginia, bounded to the west by the Dismal Swamp terrace, narrowly separated from the Atlantic Ocean to the east by sand dunes and marshlands, and connected to Currituck Sound in the south via the narrow Knotts Island Channel (Figure 1). Farther south, Currituck Sound is connected to the Atlantic Ocean through Albemarle Sound and Oregon Inlet (Figure 2). The area referred to as the Back Bay watershed encompasses surrounding uplands with numerous tributary creeks, as well as Back Bay itself, which is dotted with islands and rimmed with dunes, wetlands, and uplands. As part of a larger effort to characterize and address biological and chemical trends in Back Bay, a review of the scientific literature was performed. This document was designed and written to allow the reader to consider each section separately. It is hoped that this synthesis will provide area residents, resource managers, and public decision makers with a concise view of the history of the Back Bay ecosystem and contribute to the public dialogue that is necessary to make informed management decisions about the future of this important natural resource area.

In the last century and a half, Back Bay has undergone a general decline in water quality with wide fluctuations in the type and quantity of submerged aquatic vegetation (SAV), changes in the fish population and resident and winter waterfowl populations. Narrative and quantitative documentation point to changes and declines in both numbers and diversity of flora and fauna. Citizens residing in the Back Bay watershed, from Virginia Beach to the rural agricultural areas, as well as the U.S. Fish and Wildlife Service (FWS) as trustee of Back Bay National Wildlife Refuge, local and State agencies, public and private researchers, and environmental groups share growing concerns over the declines in the submerged aquatic vegetation,

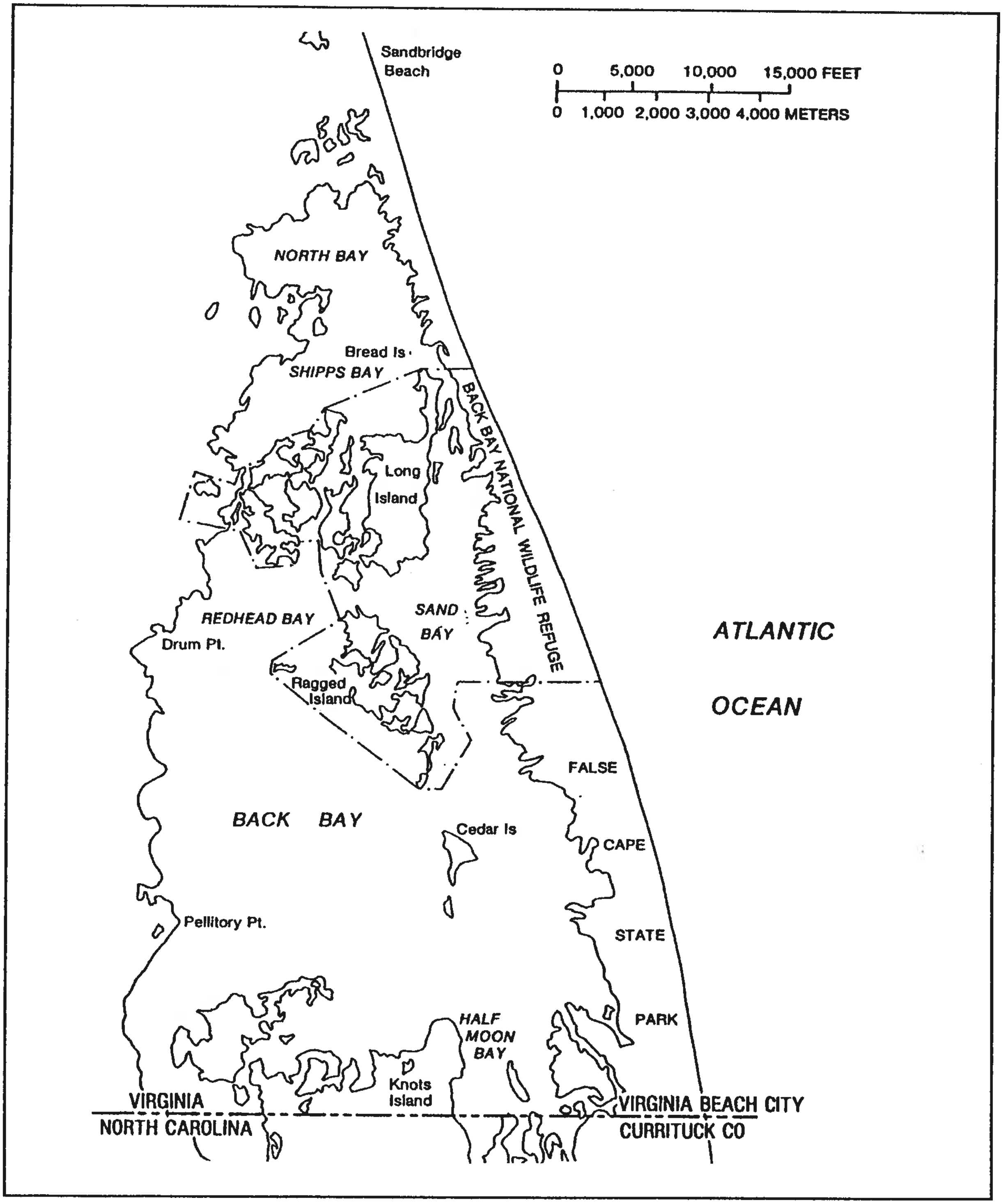


Figure 1. Map of Back Bay, Virginia

Source: U.S. Dept. of Interior, Geological Survey, 1990

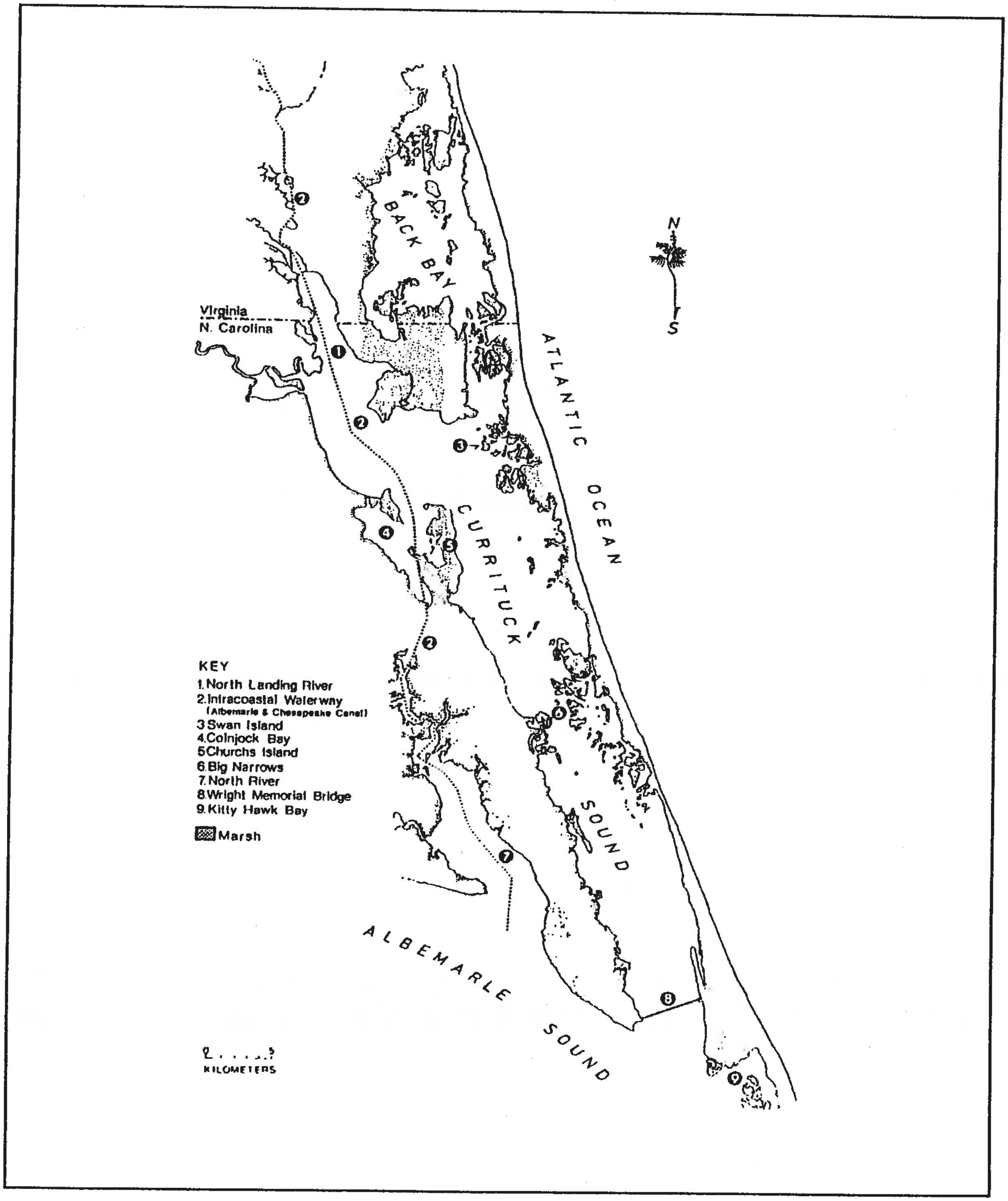


Figure 2. Regional map of Back Bay, Virginia, Currituck Sound and Abemarle Sound, North Carolina

Source: Davis and Brinson. 1983. in J. Aquatic Plant Management.

fish, and waterfowl populations. This mutual concern sparked the "Back Bay Initiative", which was proposed as a multi-year effort to define and address the causes of natural resource declines in the Back Bay ecosystem.

The Back Bay Initiative has focused on improving the overall quality of fish and wildlife habitat in the watershed. This goal has been pursued through a multi-faceted approach, including contaminants investigations, reviews of the scientific literature pertaining to the natural resources of Back Bay, land acquisition by Back Bay National Wildlife Refuge to expand the boundaries of habitat protected by the Refuge, creation of the proposed Agricultural Reserve Program to purchase development rights easements on private agricultural lands, and activities to control the invasive common reed which is highly competitive with native plant species for habitat.

There are many agencies and organizations interested in preserving the natural resources of Back Bay. Many are currently engaged in projects to enhance Back Bay habitat. The U.S. Soil Conservation Service and the Virginia Division of Soil and Water Conservation have worked together to locate landowners interested in conservation practices. The FWS and the Virginia Department of Game and Inland Fisheries (VDGIF) have cooperated to restore wetlands on private lands. Southeastern Association of Virginia's Environment (SAVE), a coalition of concerned individuals, organizations, and businesses dedicated to preservation of the total environment of southeastern Virginia, has been a leader in environmental conservation and land use planning. The ad hoc Southern Watersheds Committee, a coalition of local governments, including Virginia Beach government agencies, farm, and conservation interests, has proposed the Virginia Beach Agricultural Reserve Program (ARP). The ARP is an agricultural land banking program to preserve agricultural lands. ARP will seek to promote and enhance agriculture as an important local industry integral to a diverse economy. The Virginia Beach Chapter of the

Audubon Society supports and provides programs for the public at Back Bay National Wildlife Refuge. The Friends of Back Bay have worked to enhance public understanding of the value of the natural resources of the Back Bay watershed. The Virginia Department of Conservation and Recreation (VDCR) is working cooperatively with Back Bay National Wildlife Refuge (Refuge) on a Habitat Demonstration Project funded by the U.S. Environmental Protection Agency, with matching funds from the FWS and VDCR. This Project includes sites in the Refuge, North Landing River Preserve System, islands owned by the U.S. Army Corps of Engineers in the North Landing River, and Northwest River Park where herbicide use followed by prescribed burning is used to control the common reed, Another cooperative venture, sponsored by the FWS and implemented by Old Dominion University and the Back Bay National Wildlife Refuge, is an on-going Stormwater Monitoring Project to quantify the solids and nutrient load from Back Bay tributaries to Back Bay during storm events. The Virginia Institute of Marine Science works annually with Refuge personnel on sea turtle population enhancement.

As another part of this Back Bay Initiative, the FWS undertook a review of the literature in order to present an overview of status and trends of water quality and natural resources in Back Bay. The results of the literature review are presented in this document. This document provides an overview of the trends up to the present time, as determined through a review of the scientific literature, records maintained by Back Bay National Wildlife Refuge, and reports of others who have chronicled the changes in natural resources of Back Bay.

## AN HISTORIC LOOK AT BACK BAY, VIRGINIA

Historical accounts of the changes in abundance of underwater plants, or submerged aquatic vegetation, in Back Bay have often attributed those fluctuations to changes in water quality, in particular, salinity. Water quality studies conducted over the years in Back Bay and its tributaries are listed chronologically in Table 1. Although a definite link has yet to be established between salinity and the abundance of submerged aquatic vegetation, it is true that Back Bay has experienced great fluctuations in salinity. Saltwater from the Atlantic Ocean has intruded into Back Bay at different times. Naturally-occurring inlets across False Cape, overwash from offshore storms, flow into the south end of Currituck Sound and into the North Landing River from the Albemarle and Chesapeake Canal, and the Little Island Park pump station have all contributed saltwater to Back Bay. Table 2 summarizes important historical events in Back Bay, many of which relate to saltwater intrusion. Except for the more recent construction of the Little Island Pump Station in 1965, these past events and associated changes in water quality were best described by Sincock et al. (1965a-d).

The last naturally occurring inlet into Currituck Sound closed about 1830. With the closing of the Currituck Inlet, Weiland (1897; cited in Sincock *et al*. 1965a) reported that upwards of 100 square miles of shallow brackish -saltwater was converted to relatively freshwater, and a previously valuable oyster bed was replaced by submerged aquatic vegetation, freshwater fisheries, and increased waterfowl use within a few years. However, Sincock et al. noted that it is uncertain whether waterfowl use actually increased significantly after the closing of Currituck Inlet. During this latter part of the century, a variety of underwater plants blanketed Currituck Sound. In 1859, the Albemarle and Chesapeake Canal was constructed by a private company. As part of the Intracoastal Waterway, the canal linked Norfolk Harbor and the Elizabeth River with the North

**TABLE 1. Water quality studies in Back Bay, Virginia and its tributaries.**

| DATE | ORGANIZATION | PARAMETERS | LOCATION |
|---|---|---|---|
| 1925 - 1924 | Game Preservation Association | salinity | Knotts Island (9 sample sites) |
| 1946 | VPISU | salinity | Back Bay NWR (9) |
| 1949 - 1955 | USACE | salinity | Knotts Island (1), North Bay (1) |
| 1953 - 1956 | Anonymous | salinity | Redhead Bay (1) |
| 1958 - 1963 | USFWS, NCWRC, VDGIF | salinity, pH, alkalinity, turbidity, light penetration, metals, nutrients | Back Bay, Currituck Sound (60 sample sites) |
| 1965 - 1977 | USFWS | salinity, turbidity | Back Bay (22 sample stations) |
| 1972 - present | VWCB | pH, DO, conductivity, nutrients | Back Bay and creeks (17 sample sites) |
| 1978 - present | VDGIF | salinity, turbidity | Back Bay (24 sample sites) |
| 1977 - 1988 | USGS | light attentuation, TSS, turbidity, chlorophyll-a | Back Bay, North Bay (7 sample sites) |
| 1983 | Roy Mann Associates | pH, nutrients, TSS, turbidity | Back Bay, North Bay, creeks (20 sample sites) Back Bay (6 sample sites) |
| 1986 - 1989 | VDGIF, Back Bay Restoration Foundation | TSS, nutrients | Back Bay (6 sample sites) |
| 1991 | USFWS | pH, DO, conductivity, sediment metals and pesticides | Back Bay and tributaries (7 sample sites) |
| 1993 - 1994 | USFWS | nutrients, sediments, turbidity | |

VPISU Virginia Polytechnic Institute and State University
USFWS United States Fish and Wildlife Service
NCWRC North Carolina Wildlife Resource Commission
VWCB Virginia Water Control Board
VDGIF Virginia Department of Game and Inland Fisheries
USGS United States Geological Survey

**TABLE 2. Historical events related to the water quality of Back Bay, VA**

| | |
|---|---|
| 1600s | Open ditch drainage systems constructed in Back Bay watershed |
| 1657 | Old Currituck Inlet opens |
| 1728 | Old Currituck Inlet closed |
| 1713 | New Currituck Inlet opens |
| 1828 | New Currituck Inlet closed |
| 1859 | Albemarle and Chesapeake (A & C) Canal constructed |
| 1890 | Princess Anne Road causeway to Knotts Island constructed |
| 1917 | Great Bridge locks on the A & C Canal opened (much dredging during 1914-19) |
| 1920 | Corey's Ditch constructed to mitigate blockage by Princess Anne Road causeway |
| 1929 | Bourn report completed |
| 1932 | Great Bridge locks on the A & C Canal closed |
| 1933 | Hurricane |
| 1935 | Dune stabilization of False Cape completed by Civilian Conservation Corps. |
| 1936 | Hurricane |
| 1938 | Back Bay National Wildlife Refuge established |
| 1955 | Hurricane |
| 1958 | Back Bay-Currituck Sound Study initiated |
| 1960 | Hurricane |
| 1961 | Mackay Island National Wildlife Refuge established |
| 1962 | City of Virginia Beach incorporated |
| 1962 | "Ash Wednesday Storm" |
| 1963 | Filling of the Sandbridge Marshes initiated (completed - 1965) |
| 1964 | Eurasian watermilfoil likely introduced |
| 1964 | Back Bay-Currituck Sound Study completed (Sincock et al. 1965) |
| 1965 | City of Virginia Beach initiates saltwater pumping at Little Island Park |
| 1965-68 | Dredging of Hell's Point Creek, proposed to dredge to Rudy Inlet |
| 1974 | Little Island pump shutdown and apparently not fully operational until 1978 |
| 1977 | Little Island pump burned down |
| 1978 | Little Island pump replaced and operational until 1987 |
| 1982 | Comprehensive Plan including "Green-line" adopted by City of Virginia Beach |
| 1984 | Mann Management Plan for Back Bay, Virginia completed |
| 1987 | Little Island Park pump terminated |
| 1987 | Albemarle-Pamlico Estuarine Study begun by EPA, NC and VA |
| 1990 | Back Bay Ecological Symposium |

Landing River. The U.S. Army Corps of Engineers (Corps) purchased the Albemarle and Chesapeake Canal and the lock at Great Bridge, Virginia, in 1912. As of April 1917, the Great Bridge lock was left continuously open until new locks were constructed and put into operation in August 1932. During this 15-year period, highly saline and polluted waters reportedly flowed into Currituck Sound. The Great Bridge lock was restored to operation in 1932, in part, because of a report submitted by Warren S. Bourn of the Boyce Thompson Institute for Plant Research to the Back Bay Game Preservation Association in 1929. During a 4-year study of the canal and Back Bay, Bourn reported that submerged aquatic vegetation, primarily sago pondweed (Potamogeton pectinatus) and wild celery (Vallisneria americana), had been permanently damaged in 70% of the area and that fish harvests were 10% of the 1918 levels. The mean salinity during 1925-30 ranged from 1.2 - 3.6 parts per thousand; between 1930-33, mean salinity increased to 6 - 9 parts per thousand (Norman and Southwick 1991*a*).

Much of the literature reports that there was a dramatic decrease in submerged aquatic vegetation during the 1920s. During a U.S. Fish and Wildlife Service survey in October 1924, Sperry (cited in Sincock et al. 1965) reported that "the greater part of the open water in Red Head Bay, Sandy Bay, and Big Bay was entirely bare of submerged plant growth." By August 1926, Sperry found that "there were practically no submerged plants...." and "further search.... revealed only an occasional submerged plant." An anecdotal report by H.H. Waterfield (1951), Chief of Survey Branch, Army Corps of Engineers, Norfolk District, stated that submerged aquatic vegetation "noticeably began to disappear" in 1923-24.

Beginning in 1914, and continuing throughout the 1920s, considerable dredging was performed in the Albemarle and Chesapeake Canal and vicinity. Dredging activities cause, at a minimum, an acute increase in turbidity. The U.S. Army Corps of Engineers dredged 10 million cubic yards of sediments from the Albemarle and Chesapeake Canal and the North Landing River during

1914-19. Privately-funded dredging of Back Bay also occurred during the 1920s. In particular, Corey's Ditch was constructed in 1920 to mitigate for the blockage of water flow under the Princess Anne Road causeway (built in 1890) that connected Knotts Island to the mainland. Increased turbidity from the suspended solids of dredging activities occurred concomitantly with the intrusion of salty and polluted water through the Albemarle and Chesapeake Canal.

At about the same time that the lock on the Albemarle and Chesapeake Canal was being closed in 1932, the Civilian Conservation Corps was stabilizing the dune system on False Cape (1933-35). The results of these two coincidental events was that polluted water from Norfolk Harbor was prevented from entering Back Bay and overwash of highly saline ocean water into Back Bay was lessened. Anecdotal observations of Back Bay during this period were summarized by Sincock et al. (1965) as follows: "the exclusion of saltwater by construction of the sand-fences prior to 1935, and the restoration of the locks in the Albemarle and Chesapeake Canal, were [strongly believed to be] instrumental in destruction of the aquatic vegetation." This interpretation was directly contradictory to that of other Service biologists and Bourn, who had attributed the decline in submerged aquatic vegetation to the intrusion of saltwater and/or polluted waters.

Salinity data collected by the Back Bay Game Preservation Association during the 1930s suggest that salinity fluctuated widely, presumably because of hurricanes in 1933 and 1936. After the August 1933 storm, which forced saltwater over False Cape, mean salinity increased to 11.4 parts per thousand and remained near 10 parts per thousand until the following spring; by spring 1934, mean salinity was 3 - 4 parts per thousand. Immediately after the October 1936 storm, mean salinity increased to 6.5 parts per thousand; by spring 1938, mean salinity was once again lowered to 1.2 parts per thousand (Norman and Southwick 1991*a*).

A review of existing documentation reveals no significant change in water quality or intrusion of saltwater occurred during the 1940s and 1950s. The few salinity records that exist for Back Bay during this period suggest that Back Bay was fresh to slightly brackish. Salinity measurements ranged from 0.6 - 1.0 parts per thousand in 1946 (Chamberlain 1948) and 0.5 - 1.2 parts per thousand during 1949-56 (Robin 1955, Sincock et al. 1965; cited in Norman and Southwick 1991).

During 1954 and 1955, four hurricanes caused saltwater intrusion into Currituck Sound (Barber 1955; cited in Sincock et al. 1965). Although there are no records of the salinity in Back Bay at the time, submerged aquatic vegetation and waterfowl populations were relatively elevated (Settle and Schwab, 1991).

The information collected from the 1932 restoration of the locks to the 1950s shed new light and raised new questions on the historical problems with water quality, fish, and submerged aquatic vegetation populations. Martin et al. (1956); wrote that "in recent times there have been major shifts of opinion regarding conditions in the Back Bay area." Before 1932, residents protested the absence of a lock in the canal, whereas, in the 1950s, they blamed flooding of farms largely or partly on the lock. Navigation interests had opposed installation of a lock on the grounds that it would hinder boat traffic. However, in the 1950s they regarded its removal as undesirable because of dangerous currents that tides and wind would bring into the canal. Regarding salinity, prior to 1932, opinion was that the canal admitted too much saltwater into Back Bay. However, by 1950, the consensus seemed to be that insufficient salinity was responsible for the decline in submerged vegetation.

From 1958 - 1964 the U. S. Fish and Wildlife Service (FWS), the Virginia Commission of Game and Inland Fisheries (VCGIF), and the North Carolina Wildlife Resources Commission conducted extensive surveys of submerged aquatic vegetation, waterfowl, fish, and water quality in Back Bay and Currituck Sound (Sincock et al. 19650a-d). Many of the sampling stations have continued to be monitored after 1964 by FWS and VCGIF personnel, and the submerged aquatic vegetation and total waterfowl data represent the best quantitative record of changes in Back Bay during the past three decades (Figure 3).

On March 7, 1962, the "Ash Wednesday Storm" was responsible for the first documented, large scale intrusion of saltwater into Back Bay since the 1930s. The Back Bay-Currituck Sound study was being conducted at this time and changes in salinity and other water quality parameters were documented before and after this storm. Immediately following the storm, Back Bay salinity near overwash zones was as high as 26 parts per thousand. After two weeks of mixing, mean salinity in the Bay declined to 4.7 parts per thousand. Mean salinity further decreased to 1.6 - 1.9 parts per thousand by 1963, and by May 1965, mean salinity was 0.7 parts per thousand (Norman and Southwick 1991*a*). Although midwinter waterfowl populations remained moderately high during this period, submerged aquatic vegetation declined steeply after 1963. Coincidentally, Eurasian watermilfoil (Myriophyllum spicatum) was first observed in the vicinity of Swan Island during the summer of 1964 (Davis and Brinson 1983). Davis and Brinson (1983) suggested that salinity-induced decreases in turbidity after the "Ash Wednesday Storm" allowed for the subsequent irruption of watermilfoil during 1966 - 1967. Settling of suspended silts and clay particles is enhanced in brackish or salty water due to flocculation which occurs in the presence of chloride ions.

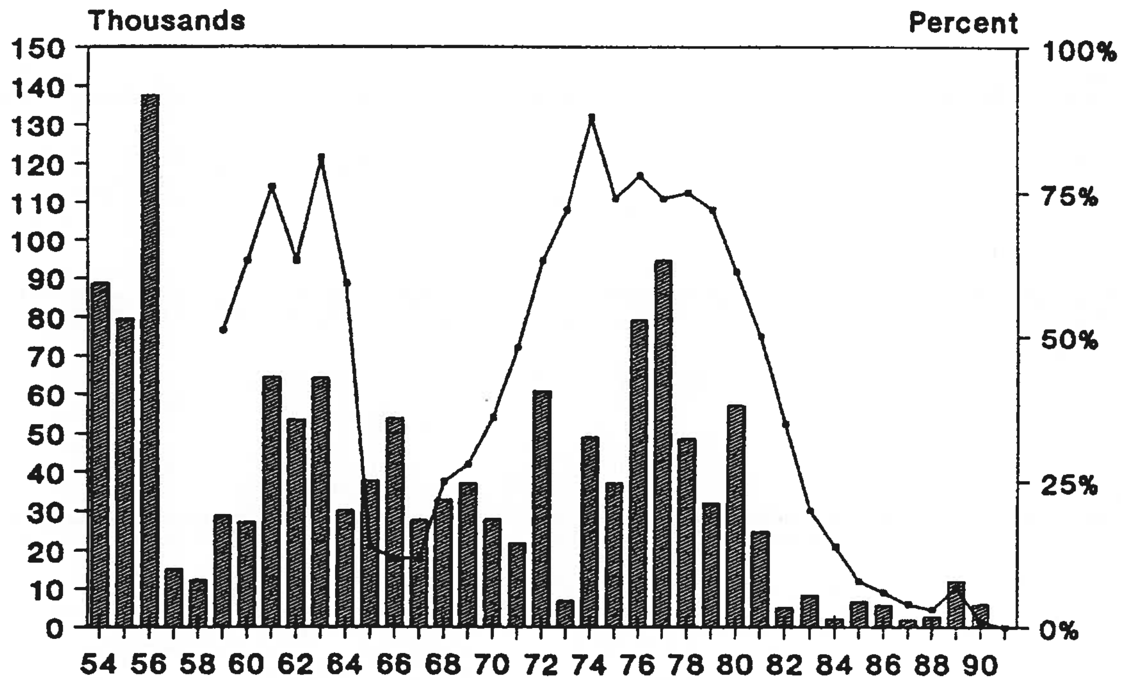


Figure 3. Total waterfowl and percent frequency of SAV in Back Bay, Virginia.

Source: Settle and Schwab, VDGIF, 1990

In 1964, the City of Virginia Beach initiated a program to maintain the salinity of Back Bay at ten percent of seawater in order to promote sediment flocculation, thereby improve water quality, and enhance submerged aquatic vegetation growth. Saltwater was pumped from the Atlantic Ocean to Shipps Bay by a pump station that was constructed at the Little Island Coast Guard Station. The pump had a capacity of 25,000 gallons per minute and was intended to be operated continuously except for maintenance (Mann 1984). This artificial introduction of seawater raised the salinity of Back Bay from 0.7 parts per thousand in May 1965 to 3.9 parts per thousand by August 1965. Over the next 10 years the salinity varied, but generally ranged from 2.0 - 3.0 parts per thousand until late 1974 (Norman and Southwick 1991*a*). Salinity declined during 1975 to 0.4 - 0.5 parts per thousand because of intermittent operation of the pump. The longest interruption occurred between May 1977 and August 1978, after a fire destroyed the pier and pump station (Mann 1984). Between 1979 and 1987, renewed pumping operations kept mean salinity between 3.0 and 4.0 parts per thousand. The Little Island Pump Station was closed permanently in September 1987, in part, because the Virginia Commission of Game and Inland Fisheries persuaded the City of Virginia Beach that declining freshwater game fisheries were associated with high salinity (Southwick and Norman 1991). By December 1989, mean salinity had declined to 0.7 parts per thousand (Norman and Southwick 1991*a*).

Submerged aquatic vegetation occurrence peaked in 1973, and thereafter declined, despite the operation of the saltwater pump and the attempted introduction of hydrilla (Hydrilla verticillata) in 1986 (Schwab et al. 1991). It became apparent in the late 1980s that changes in salinity alone could not explain changes in submerged aquatic vegetation, at least in recent times. In fact, changes in salinity over time did not necessarily correlate with the trends in abundance and decline of submerged aquatic vegetation. The interest of many agencies and individuals in the fluctuating trends of natural resources in Back Bay resulted in the Back Bay Initiative.

## STATUS AND TRENDS IN BACK BAY, VIRGINIA

### Turbidity

Secchi disc depth readings have been used widely as indicators of water clarity. Use of a Secchi disc in Back Bay to record water clarity has been a relatively recent addition to the records kept on Back Bay natural resource trends. Monthly Secchi disc readings for 22 sites (two more were added in 1986) in Back Bay were recorded by the U.S. Fish and Wildlife Service from 1965-77 and by the Virginia Department of Game and Inland Fisheries after 1977. Norman and Southwick (1991*a*) reviewed temporal trends in both data sets through 1989 (Figure 4). From 1965-80, Secchi disc visibility generally ranged from 20 - 30 inches. Visibility and water clarity began to deteriorate in 1981. From 1981-84, Secchi disc depths averaged 10 inches, and during 1985-89 depths averaged less than 10 inches. Although Norman and Southwick (1991*a*) attributed this decline in water clarity to declining submerged aquatic vegetation in Back Bay, Secchi disc readings were high in the late 1960's, during a period when submerged aquatic vegetation occurrence was extremely low (Figure 5). Norman and Southwick proposed that declining SAV growth allowed for greater wind driven action to suspend sediments, as there were fewer rooted plants stabilizing the substrate. It was also proposed that reduced submerged aquatic vegetation, caused by reduced water clarity, was also aggravated further by the wind driven action observed by Norman and Southwick. Increased turbidity contributes to reduced light transmission, and reduces photosynthetic activity of submerged aquatic vegetation. Possible factors that cause turbidity include increased Total Suspended Solids and increased nutrient loads, as well as the general resuspension of unstabilized bottom sediments.

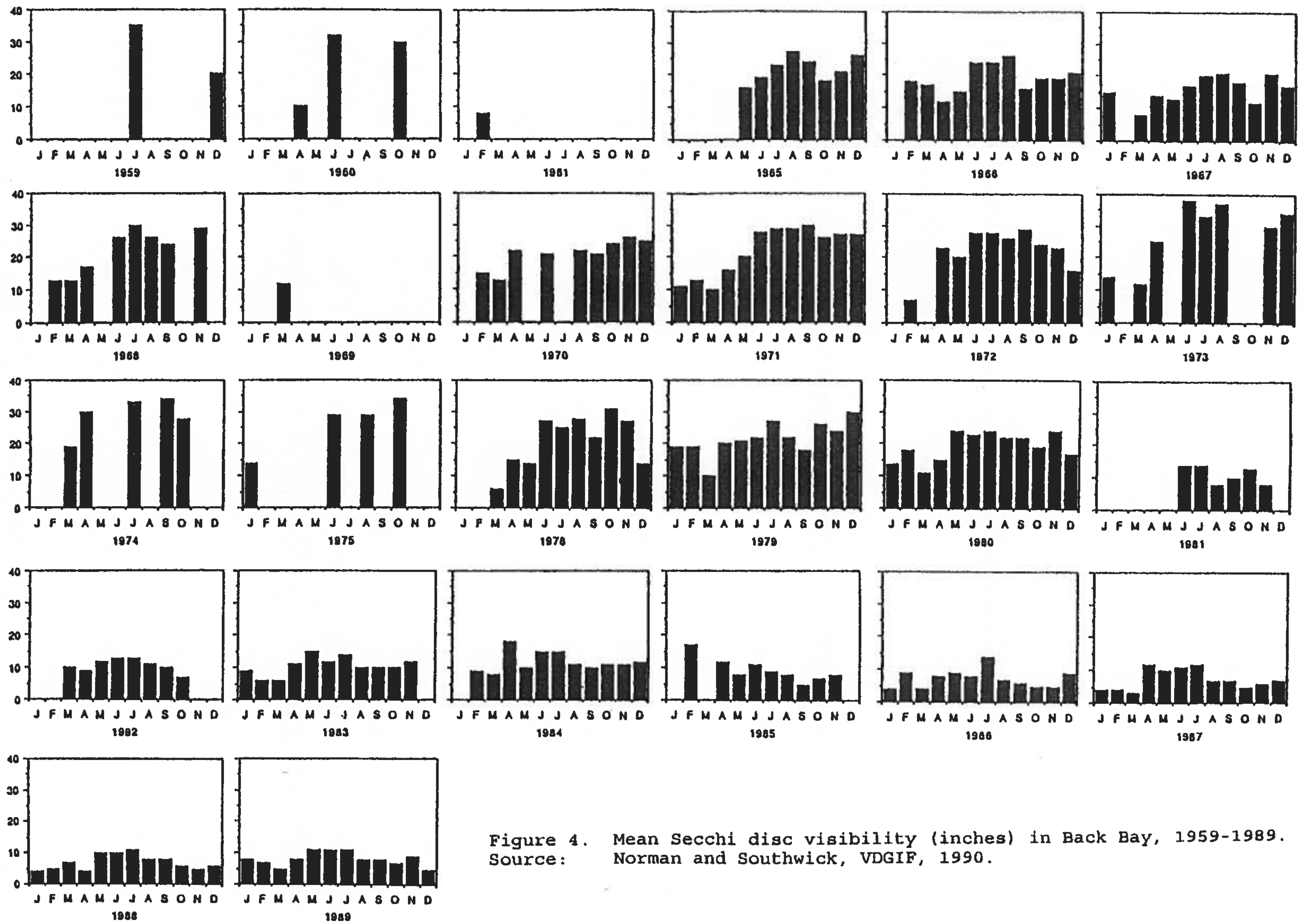


Figure 4. Mean Secchi disc visibility (inches) in Back Bay, 1959-1989.
Source: Norman and Southwick, VDGIF, 1990.

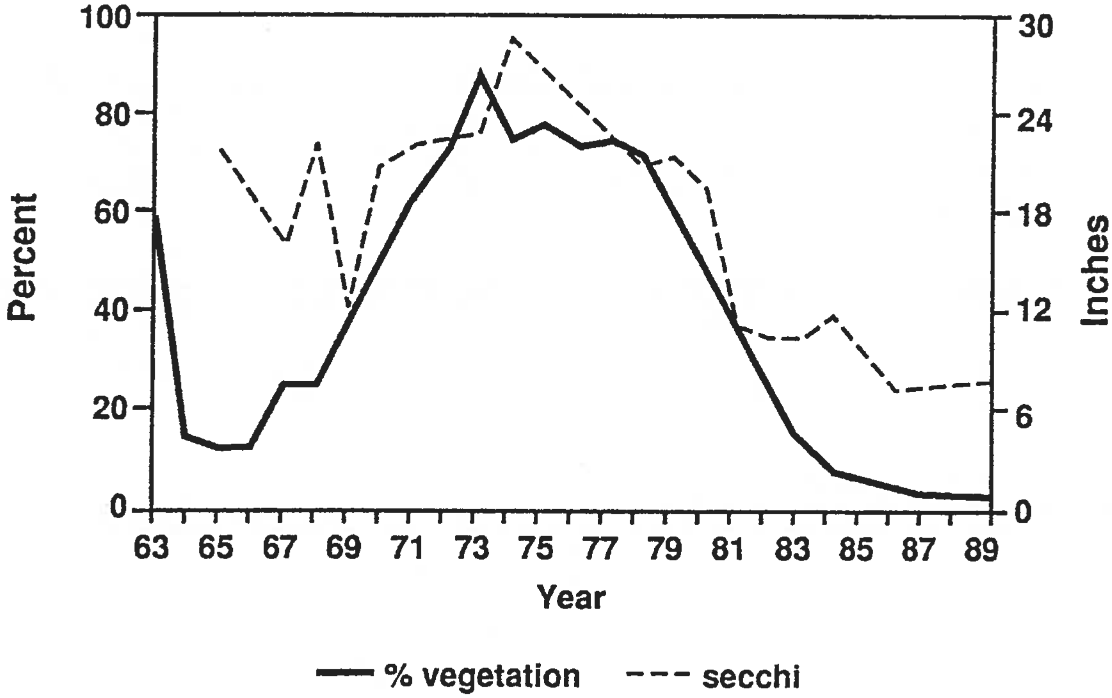


Figure 5. Comparison of mean Secchi disc visibility (inches) with abundance of submerged aquatic vegetation (% occurrence at sampling stations.)

Source: Norman and Southwick, VDGIF, 1990

The U. S. Geological Survey more recently investigated the causes of light attenuation in North and Back Bays (Carter and Rybicki 1991). Light attenuation was measured with a spectroradiometer at seven stations in 1987 and five stations in 1988; Secchi disc depth, Total Suspended Solids, and chlorophyll-*a* concentrations were measured simultaneously. Chlorophyll-*a* concentrations (i.e., phytoplankton populations) can be used as an indirect measure of eutrophication. Light-extinction coefficients ranged from 2.7 $m^{-1}$ - 19.9 $m^{-1}$, Total Suspended Solids ranged from 37 - 214 milligrams per liter, Secchi depths ranged from 0.26 - 0.44 meters, and chlorophyll-*a* from 34.5 - 88.0 micrograms per liter. A simple linear regression model suggested that Total Suspended Solids explained 85.1% of variation in the light extinction coefficient. Despite high chlorophyll-*a* concentrations for oligohaline tidal waters, there was little evidence that chlorophyll-*a*, and by implication, nutrient loads, were associated with light extinction.

In an analysis of Virginia State Water Control Board data collected over the past two decades, Alden and Priest (1991) concluded that Back Bay tributaries act as sources of nutrients (ammonia nitrogen, nitrate nitrogen, total phosphorus, orthophosphate), perhaps due to agricultural and residential runoff. That same data indicated Back Bay waters tended to be enriched with organic-rich suspended particles, probably plant detritus, sediments, or both.

Increased levels of Total Suspended Solids can arise from dredging activity, lowered salinity which results in reduced flocculation, surface runoff, and wave-induced resuspension of bottom sediments which are no longer held in place when submerged aquatic vegetation is sparse. As stated earlier, the U.S. Army Corps of Engineers dredged 10 million cubic yards from the Albemarle and Chesapeake Canal and the North Landing River during 1914 - 1919 with most of the dredged materials disposed overboard. Dredging activities in the general vicinity of the North Landing River and Currituck Sound has occurred every 2 - 4 years since that time.

Privately-funded dredging of Back Bay occurred during 1923-26 and the Sandbridge Marshes were partially filled during the 1960s (Sincock et al. 1965). Hell's Point Creek was dredged originally during the late 1960s. The impetus for creating Hell's Point Creek canal was to connect Back Bay to Owl Creek and Rudy Inlet, and ultimately, to the ocean to provide increased salinity to Back Bay. This project was also designed to provide drainage, and relieve tidal action in Back Bay. Half complete, the project eventually came to an end as the necessary easements could not be procured from all the landowners. Since those days, several bridges, including one at Sandbridge Road, seemingly preclude dredging of Hell's Point Creek. Despite the lack of turbidity measurements prior to 1959 (Norman and Southwick 1991*a*), some anecdotal observations attributed the decline in submerged aquatic vegetation in the 1920s to dredging during the 1920s (Sincock et al. 1965). Dredging activity has, at times, been blamed for high turbidity in Back Bay (Bourn and Cottam 1950). One anecdotal report by a former U.S. Army Corps of Engineers supervisor, who testified at a 1953 public meeting on the dredging of the Intercostal Waterway through Currituck, said that "there was no question in his mind that dredging was primarily responsible for the killing of the vegetation because the whole Bay became highly turbid and the plant life disappeared" (Sincock et al. 1965:20). Sincock et al. (1965) also agreed that "dredging activities in the Back Bay - Currituck Sound area were instrumental in starting the chain of events [that] resulted in excessive turbidity, silt deposits, and large, nonvegetated areas."

Although dredging causes acute increases in turbidity, the contribution of dredging to long-term increases in turbidity is questionable. For example, Bohlen et al. (1979) found that dredge-induced resuspension of sediments fell to background levels within 700 meters of a dredge and that it represented a relatively small scale perturbation of the total suspended material in the Thames River estuary in Connecticut. In a study of dredge disposal in the upper Chesapeake Bay, field measurements of primary production showed no change during and immediately after dredging, despite the presence of a turbidity plume 4 - 5 $km^2$ that lasted one to two hours after disposal completion (Chesapeake Biological Laboratory 1970; cited in Morton 1977).

The interpretation of dredging impacts on Back Bay are further confused by the concomitant intrusion of highly saline and polluted water from the Albemarle and Chesapeake Canal. Sincock et al. (1965) reported that there was no doubt that saltwater would contribute to precipitation of silts to a slight degree. They thought it unlikely, however, that salinity-induced precipitation of sediments would be sufficient to prevent the effects of turbidity caused by wave-induced sediment resuspension. At best, increased salinity would limit turbidity, thereby permitting increased submerged aquatic vegetation growth in areas where silt deposition is not a major problem.

Increased surface runoff and wave-induced resuspension of sediments also may contribute to reduced water clarity. Swift et al. (1991) developed a model of Back Bay as a sediment-accumulating sink in which equilibrium is a function of the rate of sediment supply and mean annual wave power; these authors emphasized the latter factor. X-radiographs allow comparison of radioisotope concentrations over a number of years. In this case, beginning with the baseline year 1954 for the tracers of $^{137}Cs$ and $^{210}Pb$, 1984 sediment core samples indicated that the 30-year accumulation rate was twice that of sea level rise. Because this period coincides with the Eurasian watermilfoil invasion, Swift et al. (1991) proposed that this blanket of submerged aquatic vegetation dampened wave-induced resuspension, thereby accelerating the sedimentation rate in Back Bay. Now with declining submerged aquatic vegetation, resuspension rates have increased as the Bay floor seeks to establish a new equilibrium. This model offers one explanation for the relatively high Total Suspended Solids levels in contemporary Back Bay, but it does not explain the historic loss of submerged aquatic vegetation.

Increases in Total Suspended Solids are also, in part, a function of wave-induced currents. For example, U.S. Geological Survey data showed that Total Suspended Solids were higher in 1988 than 1987, which coincides with stronger recorded winds over Back Bay, while the organic fraction of the Total Suspended Solids was only 20 - 30% of the total (Carter and Rybicki 1991). Presumably, this occurred because proportionately larger, inorganic soil particles were resuspended or kept in suspension by wind-induced waves in 1988. On the other hand, perhaps Swift et al. (1991) inadequately considered increased surface runoff from the developing watershed in their sediment budget. Currently, the U.S. Fish and Wildlife Service is conducting a water quality monitoring project to quantify nutrient and sediment input to Back Bay from its tributaries during storm events.

In summary, existing information on turbidity in Back Bay provides the following conclusions:

- There are virtually no measurements of turbidity prior to 1959.
- Turbidity, as measured by Secchi disc, has increased since 1981, and mean Secchi depths were 20 - 30 inches during 1965-80, but have been less than or equal to 10 inches since 1981.
- Recent studies suggest that Total Suspended Solids account for much of the variation in light attenuation.
- Potential sources of increased Total Suspended Solids include dredging activity, low salinity which results in decreased particulate precipitation, increased surface runoff, and wave-induced resuspension of bottom sediments. The relative contributions of each are not known.
- Abundant submerged aquatic vegetation reduces turbidity through wave and current attenuation, thus, trapping sediments and enhancing conditions for further submerged aquatic vegetation growth. The factors that cause variation in submerged aquatic vegetation in Back Bay are still being investigated.

## Nutrients and Contaminants

There are many references, both historical and current, relating to polluted waters entering the Currituck Sound and Back Bay. Bourn (1929) succinctly summed up the thoughts of the day on the subject: "... Into the shallow waters of the Sound there is an almost incessant flow of sewage and industrially polluted water from Norfolk Harbor." Bourn continues in his 1929 report to say "...Currituck Sound receives the direct southward flow of the Albemarle and Chesapeake Canal with the refuse, sewage, and industrial pollution from areas contiguous to Hampton Roads..." The question of unnaturally high levels of contaminants in the Back Bay is certainly not a recent one.

Observed changes in submerged aquatic vegetation abundance in Back Bay may be partially the result of increased nonpoint source pollution in the tributaries from the developing watershed. Nonpoint source runoff carries pollutants which contribute to reduced water clarity and quality. Non-point source pollution is characterized by sediments and nutrients, and contaminants such as heavy metals and petroleum compounds. In 1972, the Virginia Water Control Board initiated a survey of 19 water quality parameters at 17 stations throughout the Back Bay watershed. In a recent analysis of the two decades of data, Alden and Priest (1991) found that Total Kjeldahl Nitrogen (TKN) levels had increased, and both TKN and Total Suspended Solids loads were higher in Back Bay than in the tributaries. Tributaries tended to be enriched in nitrogen (ammonia nitrogen and nitrate nitrogen) and phosphorus (total phosphate and orthophosphate). These data suggest that tributaries act as sources of nutrients, possibly due to agricultural and residential runoff. Sampling of Back Bay in 1986-89 showed Back Bay concentrations of Total Suspended Solids and Total Kjeldahl Nitrogen higher than U.S. Environmental Protection Agency reference levels (Norman and Southwick 1991*b*). Back Bay waters tended to be enriched with organic-rich suspended particles, probably plant detritus, sediments, or both. Recently, Dr.

Burkholder of North Carolina State University (personal communication) has found that certain submerged aquatic vegetation react very differently to high levels of nitrate nitrogen, a common contaminant associated with polluted waters. One species of SAV, widgeon grass (Ruppia maritima), which is found in Back Bay, appears to thrive in a nitrate nitrogen enriched environment, whereas other sea grasses such as eelgrass (Zostera marina), (not documented in Back Bay) are metabolically unable to deal with those same nitrate enriched environments. This work may have implications for submerged aquatic vegetation in Back Bay. It is possible that restoration efforts using widgeon grass may be effective in nitrogen rich waters. Possibly some species of submerged aquatic vegetation which are in decline in Back Bay may be unable, like the eelgrass, to deal with high nitrate nitrogen levels. It has been a general observation, that excess nutrients can promote algal blooms which in turn diminish light penetration thus, limiting SAV growth (Koifold 1903; Swingle 1947; Twilley et al. 1985; Wetzel 1975.)

Alternatively, another theory is that low nutrient availability in Back Bay sediments may be limiting submerged aquatic vegetation growth. In 1987-88, nutrient and heavy metal concentrations were measured in sediment core samples from 12 sites in Back Bay (Mize 1988). Based on a comparison of nutrient requirements for terrestrial vascular flora, Back Bay sediment concentrations of phosphorus, calcium, potassium, and magnesium, boron, and zinc may limit submerged aquatic vegetation growth. Sincock et al. (1965) similarly reported that growth may be limited by concentrations of phosphorus and potassium. Mize (1988) suggested that the availability of these nutrients for plant uptake may be further restricted by the relatively high pH (6.86 - 8.35) of these sediments. The addition of seawater of different salinities (1.4 - 20% of seawater) to Back Bay sediment samples generally did not alter pH or nutrient availability (Sincock et al. 1965).

Some contaminants may be chronically present in Back Bay at toxic concentrations; alternatively, critical concentrations may only occur during high precipitation events. In 1991, the U.S. Fish and Wildlife Service (FWS) assessed sediment concentrations of metals, organochlorines, polynuclear aromatic hydrocarbons (PAHs), and chlorphenoxy herbicides from six sites, including the mouths of four tributary streams, in order to evaluate the possible contribution of watershed contaminants to Back Bay. Although somewhat elevated levels of aluminum, magnesium, iron, and zinc were found in some areas, no other contaminants were found to occur at significantly elevated levels in sediment samples. Furthermore, bioassays of sediment samples did not demonstrate significant toxicity to sago pondweed (Potamogeton pectinatus) or an amphipod (Hyalella azteca)(Seeley and Stilwell 1994).

The FWS has begun a multi-year water quality monitoring project to quantify the amount of solids and nutrients entering Back Bay from tributaries during storm events. The parameters being monitored include: Total Suspended Solids, Total Suspended Solids-Volatile Fraction, Total Dissolved Solids, Total Dissolved Solids-Volatile Fraction, Ortho-phosphate, Total Phosphorus, Nitrate Nitrogen, Ammonia Nitrogen, Total Kjeldahl Nitrogen, Turbidity, and Chlorophyll-a.

In summary, the existing information on nutrients and contaminants in Back Bay provides the following conclusions:

- Tributaries are rich in nutrients and are likely contributing to nutrient rich conditions in Back Bay.
- Back Bay has elevated levels of suspended solids and Total Kjeldahl nitrogen, as indicated by comparison to past records and USEPA recommended reference levels.
- Recent FWS testing for sediment contaminants, such as metals, organochlorines, polyaromatic hydrocarbons, and herbicides, revealed no significantly elevated levels.

- Results of the FWS's on-going, multi-year study of nutrient and sediment contributions to Back Bay from tributaries during storm events, will be a significant addition to the background of information concerning contaminants in Back Bay.

**Submerged Aquatic Vegetation**

The decline of underwater plants, collectively referred to as submerged aquatic vegetation (SAV), in Back Bay is a contemporary issue of concern because of its association with waterfowl use, fish, and water quality. SAV provides essential food and shelter for diverse communities of waterfowl, fish, and shellfish, not to mention a multitude of invertebrate animals. Since 1958, submerged aquatic vegetation, sometimes referred to as "grasses", has been sampled annually, except for 5 years (1979, 1982-82, 1985-86). Vegetation sampling transects were established in 1958 by the U.S. Fish and Wildlife Service (FWS) and later sampled by the Virginia Department of Game and Inland Fisheries (VDGIF) (Sincock et al. 1965). Submerged aquatic vegetation frequency and species composition are determined in September - November with triplicate two-square-foot grab samples collected at 500 foot intervals along eight transect lines. Records of wet and dry weights were discontinued in 1974. Schwab et al. (1991) recently reviewed temporal trends in both FWS and VDGIF data sets, and Mann (1984) included maps of chronological changes in SAV spatial distribution. Information prior to 1958 on submerged aquatic vegetation is restricted to a few surveys conducted by FWS personnel and anecdotal records, both of which were reviewed by Sincock et al. (1965a).

There have been three significant declines in submerged aquatic vegetation populations documented during the past 70 years. The first decline reportedly began in 1923-24, the second in 1964-65, and the third in 1979-89. The circumstances surrounding these declines were different in all three cases.

Prior to 1920's

In the early 1900s, the submerged aquatic vegetation community in Back Bay reportedly consisted of abundant sago pondweed (Potamogeton pectinatus), bushy pondweed (Najas flexilis), wild celery (Vallisneria americana), and redhead grass (Potamogeton perfoliatus). Widgeon grass (Ruppia maritima) and leafy pondweed (Potamogeton foliosus) were present but poorly distributed (McAtee 1917; cited in Sincock et al. 1965). Muskgrass (Chara spp.), an algae often mistaken for submerged aquatic vegetation, was described as almost blanketing the bottom of Currituck Sound. McAtee, in early investigations, identified the bushy pondweed, or northern naiad as it is also referred to, as N. flexilis, but Chamberlain (1948) and Sincock et al. (1965) later reported it as N. guadalupensis, southern naiad.

1920's Decline

Most of the literature is in agreement that there was a dramatic decrease in submerged aquatic vegetation during the 1920s. Based on a FWS survey in October 1924, Sperry (cited in Sincock et al. 1965) reported that "the greater part of the open water in Red Head Bay, Sandy Bay, and Big Bay was entirely bare of submerged plant growth;" sago pondweed, widgeon grass, wild celery, bushy pondweed, redhead grass, and coontail (Ceratophyllum demersum) were locally abundant in Back Bay but widely scattered in distribution. By August 1926, Sperry found that "there were practically no submerged plants in the deeper water except in sections of North Bay and, even there, the growth was restricted to a patchy carpet of young plants of N. flexilis." No sago pondweed or redhead grass was seen at that time. Further searches in Shipps Bay, Redhead Bay, Sand Bay, and most of Big Bay revealed only an occasional submerged plant. One 2 - 3 acre patch of sago pondweed and widgeon grass was observed in Big Bay, and some of the island ponds supported good growths of sago pondweed, widgeon grass, bushy pondweed, and wild celery. Sperry also noted the silicate remains of hydroids (particularly on sago pondweed), a root rot, and another malady that reduced the vitality of leaves but apparently not the roots. He concluded that "saltwater is certainly not the direct cause of damage for sago and widgeongrass, plants which ordinarily withstand a high concentration of salts, are the ones most affected." Because the diseased plants were first noticed to be affected near the mouth of the North Landing River, Sperry concluded that "the logical conclusion is that the pollution, or whatever is causing the trouble comes into the sound via the Chesapeake and Albemarle Canal" (cited in Sincock et al. 1965a).

In November 1927, McAtee reported submerged aquatic vegetation conditions that were "vastly improved over what was observed season before last." Sago pondweed showed signs of recovery, with significant growth in Back Bay and North Bay. McAtee attributed this increased growth to prevailing southerly winds that year which he claimed helped to prevent the influx of saltwater from the Albemarle and Chesapeake Canal. This is a confusing conclusion in that southerly winds would also push saltwater north from Currituck Sound (Swift et al. 1991; Bourn 1929:8-9). Perhaps Sperry was more accurate when he attributed the cause of declines to reduced quality of the water from the canal rather than highly saline waters.

In 1929, Hotchkiss prepared a field map of the vegetation in Back Bay (Figure 6). Sago pondweed, wild celery, and redhead grass were generally scarce but locally abundant in Redhead Bay, North Bay, and southwest of Ragged Island. Bushy pondweed was scattered nearly everywhere. Hotchkiss attributed the fluctuating abundance of submerged aquatic vegetation in the late 1920s to "some form of pollution - generally considered to be ... saltwater."

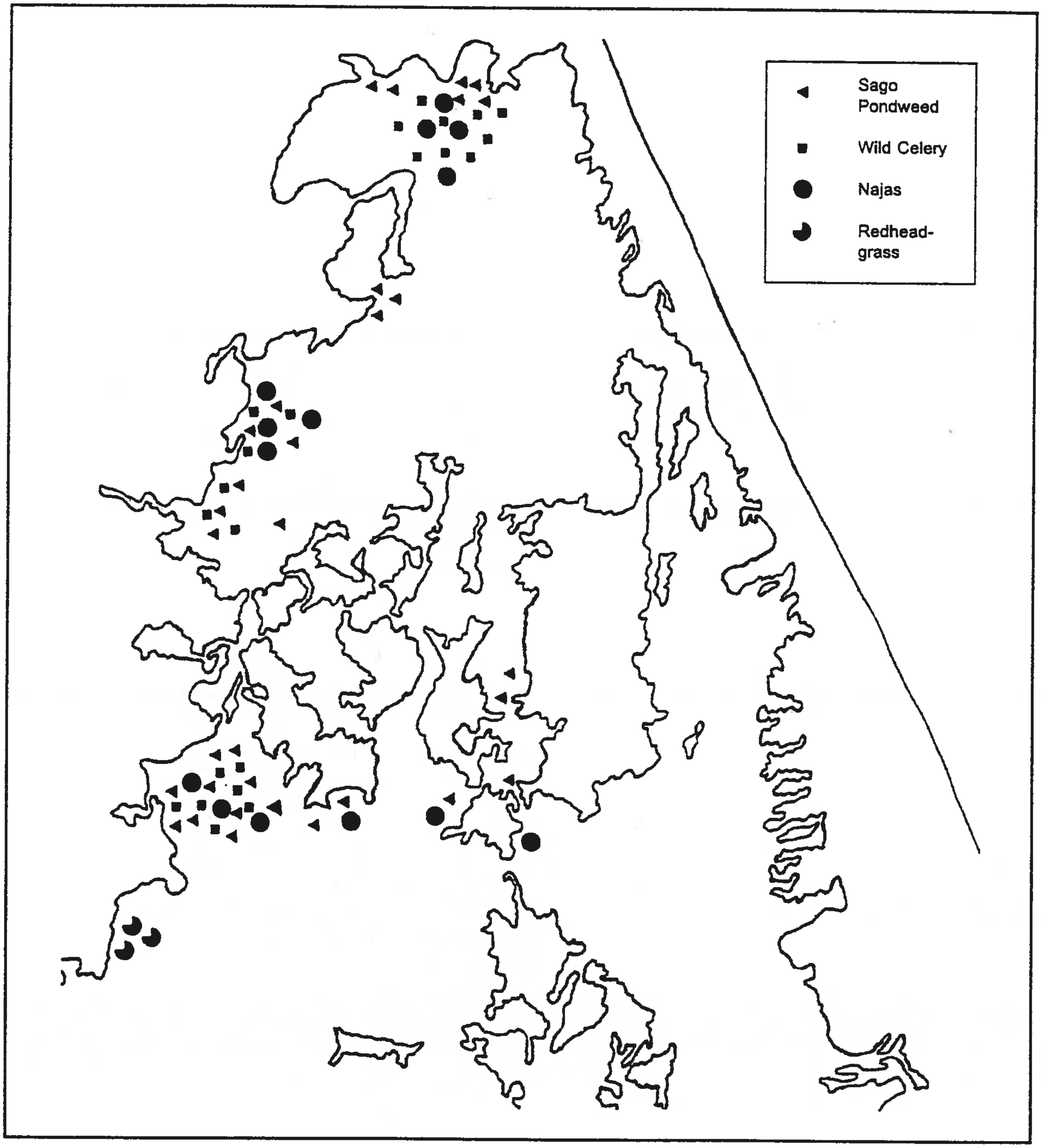


Figure 6. Map of submerged aquatic vegetation in the late 1920s in Back Bay, Virginia.

Source: Hotchkiss in U.S. Dept. of Interior, Fish and Wildlife Service, 1965; back Bay - Currituck Sound Data Report.

As these reports suggest, the cause of the 1920s submerged aquatic vegetation decline is not apparent. Resuspension of sediments from wind and extensive dredging activity during that period occurred concomitantly with the intrusion of highly saline and polluted water from the Albemarle and Chesapeake Canal. It is not apparent when submerged aquatic vegetation populations began to recover, but anecdotal records suggest the period after 1956 (Sincock et al. 1965).

The mid-1960's decline

The Back Bay-Currituck Sound Data Report documented the second major decline in SAV populations in 1964-65. In 1962, SAV frequency peaked at 81%; the dominant species were southern naiad and sago pondweed (Schwab *et* al. 1991). By 1964, submerged aquatic vegetation frequency had dropped to 14% and naiad had almost disappeared (Figure 4).

It is possible that changes in submerged aquatic vegetation frequency were associated with changes in salinity during this period. The "Ash Wednesday Storm" in March 1962 caused the first significant intrusion of saltwater into Back Bay since the 1930s. Salinities near overwash zones were initially as high as 26 parts per thousand and mean salinity did not return to pre-storm values (0.7 parts per thousand), until May 1965 ( Norman and Southwick 1991*a*).

Coincidentally, the non-native species, Eurasian watermilfoil (Myriophyllum spicatum), was first observed in the vicinity of Swan Island during the summer of 1964 (Davis and Brinson 1983). The Back Bay National Wildlife Refuge (Refuge) annually documents habitat conditions in Back Bay, particularly within the Refuge boundaries, and in 1966 reported that, "This is the year that Eurasion milfoil really spread to Back Bay." The Refuge reported in 1967 "... a tremendous increase in the amount of Eurasian milfoil." Again, in 1968 and 1969 they reported vegetation increasing and watermilfoil, covering many coves and bays, being the dominant species. Davis and Brinson (1983) suggested that saline-induced decreases in turbidity after the "Ash Wednesday Storm" resulted in the subsequent irruption of water milfoil during 1966-67. Watermilfoil was noted in trace amounts during a 1966 survey (Coggin 1966) but, by 1967, it occurred on 12% of sample stations (Coggin 1968). Since 1970, watermilfoil has become the dominant submerged aquatic vegetation species, regardless of subsequent changes in total submerged aquatic vegetation abundance (Schwab et al. 1991). Submerged aquatic vegetation frequency peaked in 1973 at 88%, a time when watermilfoil was present on 83% of stations. Although watermilfoil was the dominant submerged aquatic vegetation species during the recovery period from about 1967 through 1989, its role in this recovery is unclear. Native flora may have responded as well in the absence of possible competitive effects of an exotic species. Nonetheless, abundance of watermilfoil helps to dampen wave-induced resuspension of sediments, provides habitat for fish, and food for waterfowl.

Late 1970's Decline

The third decline in submerged aquatic vegetation abundance occurred after 1978. SAV was recorded on 50% of the stations in 1980 (Settle, 1981 cited in Schwab et al. 1991) but was completely absent by 1990 (VDGIF, unpublished data cited in Schwab et al. 1991.) In 1986 an attempt was made to introduce another non-native species, hydrilla (Hydrilla verticillata), to Back Bay in an effort to re-establish some form of submerged aquatic vegetation in Back Bay.

The causes of reduced submerged aquatic vegetation abundance during the past decade are still under investigation. Salinity has fluctuated during this period. Certainly the influx of saltwater from the Little Island Pump Station until 1987 had some effect on salinity. Water clarity began to deteriorate noticeably in 1981. Although Norman and Southwick (1991*a*) attributed this decline in water clarity to declining submerged aquatic vegetation in Back Bay, Secchi disc depth readings were high in the mid-1960s during a period when submerged aquatic vegetation occurrence was extremely low. It may be that increased turbidity has reduced submerged aquatic vegetation growth.

Generally, low submerged aquatic vegetation abundance in the past 70 years appears to be more typical than not. Submerged aquatic vegetation populations were low for at least three decades after 1923, several years in the mid-1960s, and again during the last decade. Much research has focused on the dynamics of factors that may cause submerged aquatic vegetation populations to decline. Another approach is to study which factors contribute to submerged aquatic vegetation irruptions.

In summary, information on submerged aquatic vegetation in Back Bay suggests the following conclusions:

- Submerged aquatic vegetation frequency and species composition have been monitored in the autumn almost continuously since 1958; data gaps occured in 1979, 1982-83, 1985-86. Additionally, there were a few qualitative surveys conducted by FWS personnel during the 1920s, but most of the information is anecdotal.
- There have been three well-documented declines in submerged aquatic vegetation populations during this century: 1923-24, 1964-65, and 1978-79. SAV abundance appears to have remained low for 3 decades after the 1923-24 decline. This decline has variably been attributed to intrusion of highly saline and polluted water before closure of the Albemarle and Chesapeake Canal, lack of saltwater intrusion after closure of the Canal, and high turbidity from dredging activities. The 1964-65 decline was short-lived. Since the third decline began in 1978-79, low SAV abundance has continued.
- Possible factors contributing to low abundance are low nutrient availability in sediments, and/or increased Total Suspended Solids and Total Kjeldahl Nitrogen in the water

column. It is not clear whether the high Total Suspended Solids originates from resuspension of bottom sediments or surface runoff from the surrounding watershed tributaries. Increased solids are likely a result of a combination of the factors. Current sediment concentrations of metals, organochlorines, polynuclear aromatic hydrocarbons (PAHs), and chlorphenoxy herbicides do not appear to be limiting submerged aquatic vegetation growth.

- Most recently, Back Bay National Wildlife Refuge has noted that in coves of Long Island, Ragged Island and eastern coves of the barrier spit, submerged aquatic vegetation is now showing a return from a 0% frequency of SAV in 1990.
- In this century, high submerged aquatic vegetation abundance appears to be historically atypical. Much research has focused on factors that may cause SAV population declines; another approach may be to study factors that contribute to submerged aquatic vegetation irruptions.

## Fish

There have been several studies of fish populations in Back Bay. The Virginia Department of Game and Inland Fisheries (VDGIF) collected data in 1951-52 from rotenone samples, creel surveys, a largemouth bass-tagging study, and a survey of commercial fishing operations (Rosebery 1952; cited in Sincock et al. 1965d). The U.S. Fish and Wildlife Service, VDGIF, and the North Carolina Wildlife Resource Commission conducted a similar fisheries survey during 1959-63, as part of the Back Bay-Currituck Sound study. This study also included bioassays of saline toxicity to largemouth bass (Micropterus salmoides) and bluegill (Lepomis macrochirus) (Sincock et al. 1965). The VDGIF again sampled Back Bay fish populations in 1978-81 (Norman and Southwick 1981), 1985-86 (Norman and Southwick 1987), and in 1989 (Southwick and Norman 1991). Much of the following is taken from a comprehensive review of these studies by Southwick and Norman (1991).

Of 31 fish species collected in Back Bay in 1989, 48% were considered freshwater, 45% were brackish, and 6% were marine (Table 3). Biomass estimates (kilograms/hectare) in 1986 indicated that white perch (Morone americana), spot (Leiostomus xanthurus), striped mullet (Mugil cephalus), carp (Cyprinus carpio), longnose gar (Lepisosteus osseus), sheepshead minnow (Cyprinodon variegatus), banded killifish (Fundulus diaphanus), pumpkinseed (Lepomis gibbosus), and largemouth bass (Micropterus salmoides) were the most abundant species in descending order. Three brackish species, white perch, spot, and mullet, represented 60% of the total standing crop (129.5 kg/ha).

These recent estimates of fish species richness and abundance do not appear to be inconsistent with other estimates during the past four decades. Fish species richness has ranged from 24 - 40 species (Table 3) and standing crop estimates have ranged from 94.4-153.0 kg/ha (Table 4).

TABLE 3. Fishes collected from Back Bay, 1951, 1959-62, 1978-80, 1985-86 and 1989.

Source: Southwick and Norman, VDGIF

| | Year Collected | | | | |
|---|---|---|---|---|---|
| | 1951 | 1959-62 | 1978-80 | 1985-86 | 1989 |
| **FRESHWATER** | | | | | |
| Lepisosteidae | | | | | |
| *Lepisosteus osseus* longnose gar | X | X | X | X | X |
| Amiidae | | | | | |
| *Amia calva* bowfin | X | X | X | X | X |
| Umbridae | | | | | |
| *Umbra pygmaea* eastern mudminnow | | X | X | | |
| Esocidae | | | | | |
| *Esox americanus* redfin pickerel | | X | X | | |
| *Esox niger* chain pickerel | X | X | X | X | |
| Cyprinidae | | | | | |
| *Cyprinus carpio* carp | X | X | X | X | X |
| *Notemigonus crysoleucas* golden shiner | X | X | X | X | X |
| Ictaluridae | | | | | |
| *Ictalurus catus* white catfish | | X | | X | X |
| *Ictalurus natalis* yellow bullhead | | X | | | X |
| *Ictalurus nebulosus* brown bullhead | X | X | X | X | X |
| *Ictalurus punctatus* channel catfish | X | X | X | X | X |
| Centrarchidae | | | | | |
| *Centrarchus macropterus* flier | | X | X | | |
| *Enneacanthus gloriosus* bluespotted sf. | X | X | X | X | X |
| *Lepomis gibbosus* pumpkinseed | X | X | X | X | X |
| *Lepomis gulosus* warmouth | | X | | | X |
| *Lepomis macrochirus* bluegill | X | X | X | X | X |
| *Micropterus salmoides* largemouth bass | X | X | X | X | X |
| *Pomoxis nigromaculatus* black crappie | X | | X | X | X |
| Percidae | | | | | |
| *Perca flavescens* yellow perch | X | X | X | X | X |
| **SUBTOTAL** | **13** | **18** | **16** | **14** | **15** |
| **FRESH/BRACKISH** | | | | | |
| Elopidae | | | | | |
| *Elops saurus* ladyfish | | X | | X | |
| Anguillidae | | | | | |
| *Anguilla rostrata* American eel | X | X | X | X | X |
| Clupeidae | | | | | |
| *Alosa aestivalis* blueback herring | | | X | X | X |
| *Alosa pseudoharengus* alewife | X | X | X | X | |
| *Alosa sapidissima* American shad | X | | | | |
| *Dorosoma cepedianum* gizzard shad | X | X | X | X | X |
| *Dorosoma petenense* threadfin shad | | | X | | X |
| Engraulidae | | | | | |
| *Anchoa mitchilli* bay anchovy | | | X | X | X |
| Belonidae | | | | | |
| *Strongylura marina* Atlantic needlefish | X | X | X | X | X |
| Cyprinodontidae | | | | | |
| *Cyprinodon variegatus* sheepshead minnow | | | X | X | X |
| *Fundulus diaphanus* banded killifish | X | X | X | X | X |
| *Fundulus heteroclitus* mummichog | | | | X | |
| Poecilidae | | | | | |
| *Gambusia affinis* mosquitofish | | X | X | X | X |

TABLE 3. (continued)

| | Year Collected | | | | |
|---|---|---|---|---|---|
| | 1951 | 1959-62 | 1978-80 | 1985-86 | 1989 |
| Atherinidae | | | | | |
| *Menidia menidia* Atlantic silverside | | | X | X | |
| *Menidia peninsulae* tidewater silverside | | X | X | X | X |
| Gasterostridae | | | | | |
| *Gasterosteus aculeatus* 3 spine stickleback | | | X | X | |
| Percicthyidae | | | | | |
| *Morone americana* white perch | X | X | X | X | X |
| *Morone saxatilis* striped bass | X | X | | | |
| Sciaenidae | | | | | |
| *Bairdiella chrysoura* silver perch | | | | X | |
| *Leiostomus xanthurus* spot | X | X | X | X | X |
| *Micropogonias undulatus* Atlantic croaker | | | | X | |
| Mugilidae | | | | | |
| *Mugil cephalus* striped mullet | X | X | X | X | X |
| Gobiidae | | | | | |
| *Gobiosoma bosci* naked gobi | | | | X | X |
| **SUBTOTAL** | **10** | **12** | **16** | **20** | **14** |
| **MARINE** | | | | | |
| Clupeidae | | | | | |
| *Brevoortia tyrannus* Atl. menhaden | X | X | X | X | X |
| Syngnathidae | | | | | |
| *Syngnathus fuscus* northern pipefish | | | | X | |
| Sciaenidae | | | | | |
| *Cynoscion regalis* weakfish | | | | X | |
| Pleuronectidae | | | | | |
| *Pseudopleuronectes americanus* winter flounder | | | | X | X |
| Soleidae | | | | | |
| *Trinectes maculatus* hogchoker | | | | X | |
| Cynoglossidae | | | | | |
| *Symphurus plagiusa* blackcheek tonguefish | | | | X | |
| **SUBTOTAL** | **1** | **1** | **1** | **6** | **2** |
| **TOTALS** | **24** | **31** | **33** | **40** | **31** |

TABLE 4. Comparison of standing crop data (kg/ha) for Back Bay fishes collected in rotenone samples in 1951, 1962, 1978-80, and 1986.

Source: Southwick and Norman, VDGIF, 1990.

| | 1951 | 1962 | 1978 | 1979 | 1980 | 1986 |
|---|---|---|---|---|---|---|
| **Freshwater** | | | | | | |
| Longnose gar | 0.06 | 0.37 | 19.36 | 0.03 | 0.02 | 9.65 |
| Bowfin | 3.09 | 4.37 | 0.52 | 2.57 | 1.11 | 0 |
| Eastern mudminnow | 0 | 0.10 | 0.03 | 0.01 | 0 | 0 |
| Chain pickerel (Redfin) | 0 | 0.11 | 0 | (0.21) | 0 | 0.01 |
| Carp | 11.10 | 3.92 | 1.81 | 0.15 | 0.01 | 9.78 |
| Golden shiner | 5.62 | 3.25 | 0.51 | 0.49 | 0.66 | 0.17 |
| White catfish | 0 | 0.78 | 0 | 0 | 0 | 0 |
| Channel catfish | 20.51 | 2.46 | 0 | 0 | 0 | 0 |
| Yellow bullhead | 0 | 0 | 0 | 0 | 0 | 0.28 |
| Brown bullhead | 3.65 | 2.58 | 2.65 | 1.81 | 5.51 | 0.08 |
| Flier | 0 | 0.11 | 0.22 | 0 | 0 | 0 |
| Bluespotted sunfish | 0 | 0.67 | 1.06 | 0.15 | 0.11 | 0.72 |
| Warmouth | 00.45 | 0 | 0 | 0 | 0 | |
| Pumpkinseed | 7.02 | 20.27 | 44.51 | 69.91 | 40.30 | 5.98 |
| Bluegill | 0.06 | 3.36 | 1.69 | 11.69 | 4.54 | 0.94 |
| Largemouth bass | 15.60 | 6.83 | 21.83 | 18.19 | 20.92 | 2.78 |
| Black crappie | 0 | 0 | 1.46 | 1.48 | 2.36 | 0.06 |
| Yellow perch | 2.25 | 4.82 | 7.74 | 22.26 | 10.21 | 0.33 |
| Subtotal | 68.96 | 54.45 | 103.39 | 128.95 | 85.75 | 30.78 |
| **Brackish** | | | | | | |
| Ladyfish | 0 | 0 | 0 | 0 | 0 | 0.22 |
| American eel | 0.06 | 0.78 | 1.12 | 1.82 | 2.08 | 0 |
| Gizzard shad | 0 | 0.10 | 0.28 | 0 | 11.25 | 0.20 |
| Threadfin shad | 0 | 0 | 0.01 | 0 | 0 | 0 |
| Alewife | 2.36 | 0 | 0 | 0 | 0 | 0 |
| Bay anchovy | 0 | 0 | 0 | 0.17 | 0 | 0 |
| Atlantic needlefish | 0.06 | 0.10 | 0.22 | 0.04 | 0.19 | 0.35 |
| Sheepshead minnow | 0 | 0 | 0 | 0.06 | 0.37 | 9.24 |
| Banded killifish | 0.06 | 0.67 | 0.03 | 0.25 | 0.35 | 6.57 |
| Mummichog | 0 | 0 | 0 | 0 | 0 | 0.10 |
| Mosquitofish | 0 | 0.10 | 0.01 | 0.01 | 0 | 0.29 |
| White perch | 10.26 | 6.38 | 9.17 | 2.10 | 16.24 | 33.26 |
| Tidewater silversides | 0 | 0.11 | 0.33 | 0.04 | 0.55 | 1.66 |
| Spot | 7.70 | 7.95 | 30.07 | 0 | 4.31 | 22.72 |
| Striped mullet | 8.29 | 22.96 | 5.27 | 0.53 | 3.44 | 22.11 |
| SUBTOTAL | **28.79** | **39.15** | **46.51** | **4.85** | **38.78** | **96.89** |
| **Marine** | | | | | | |
| Atlantic menhaden | 0.15 | 0.78 | 3.11 | 0 | 0 | 0.85 |
| Winter flounder | 0 | 0 | 0 | 0 | 0 | 0.96 |
| SUBTOTAL | **0.15** | **0.78** | **3.11** | **0** | **0** | **1.81** |
| TOTALS | **97.90** | **94.38** | **153.01** | **133.80** | **124.53** | **129.48** |

However, a summary of anecdotal observations (Sincock et al. 1965) suggests a more diverse and, perhaps, a more marine community prior to Roseberry's 1952 study that stated, "bass, white and yellow perch (Perca flavescens), flounder (Pseudopleuronecte sp.), spot (Leiostomus xanthurus), rock (Morone saxatilis), croakers (Micropogonias undulatus), and trout (Cynoscion sp.) were far more abundant prior to 1924, and apparently prior to 1935, than in 1951."

Recent concern has focused on decreasing populations of important recreational fish species, particularly largemouth bass. Largemouth bass were once commercially harvested in Back Bay (Roseberry 1952), and between 1977-83 more citation size (i.e., greater than 3.63 kilograms) bass were caught recreationally in Back Bay than in any other water in Virginia (Southwick and Norman 1991). However, standing crop estimates of largemouth bass were 7.5 times less in 1986 than in 1980. Furthermore, despite similar estimates of total standing crop in both years, largemouth bass accounted for 17% of the biomass in 1980, but only 2% of the biomass in 1986. Southwick and Norman (1991) attributed the recent decline in citation largemouth bass populations to reduced submerged aquatic vegetation and high salinity in Back Bay during the 1980s. There is circumstantial evidence that loss of submerged aquatic vegetation decreases adult largemouth bass survival (Figure 7). In the case of the salinity, bioassays conducted during the Back Bay-Currituck Sound study (Wollitz 1962; Tebo and McCoy 1964) showed 100% mortality of bass eggs and fry at salinities greater than 3.5 parts per thousand. Coincidently, saltwater pumping from the Little Island Pump Station maintained mean salinities in Back Bay between 3.0 - 4.0 parts per thousand through September 1987. Southwick and Norman (1991) associated recent observations of young-of-year largemouth bass in Back Bay tributaries with decreased salinity since termination of saltwater pumping.

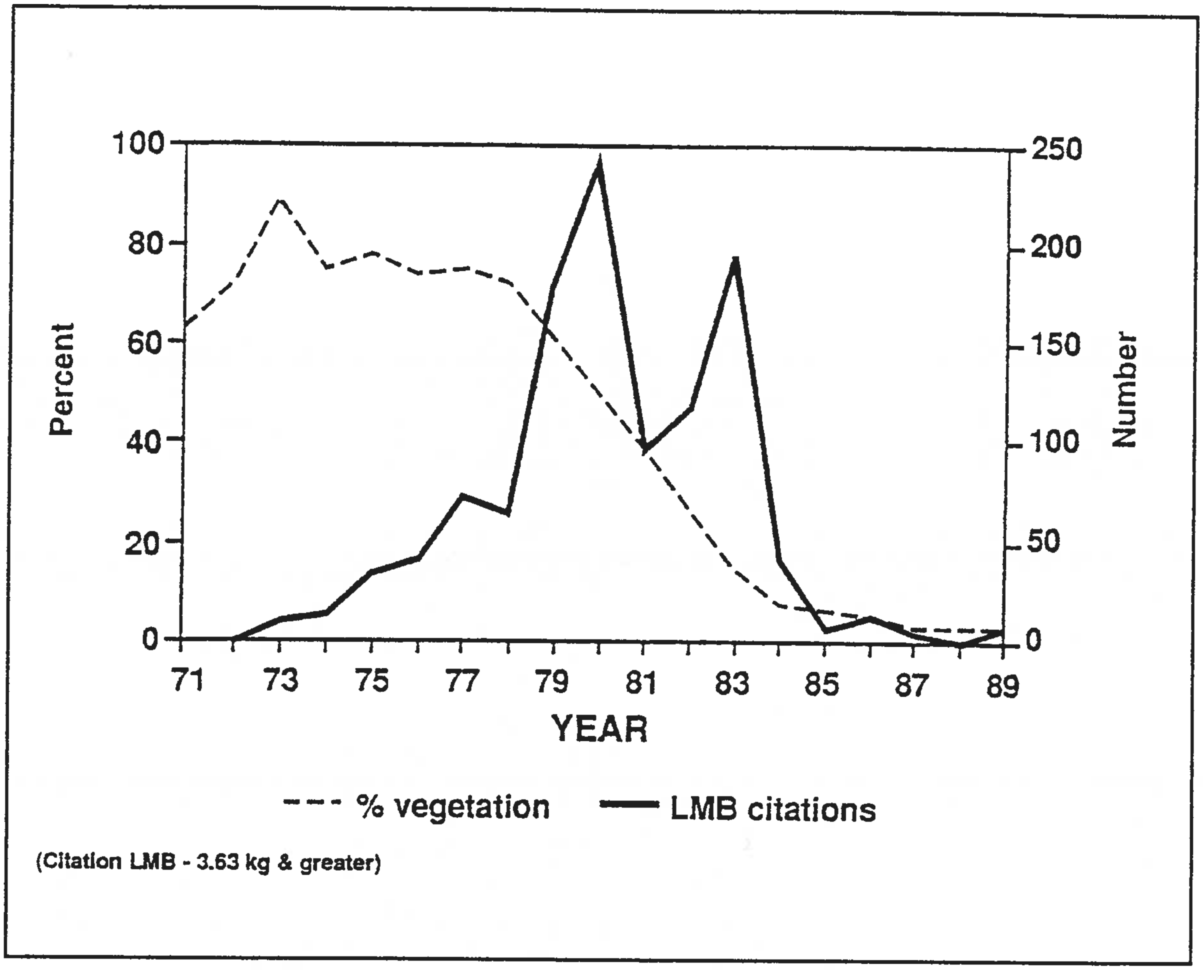


Figure 7. Abundance of submeged aquatic vegetation virsus largemouth bass citations in Back Bay, 1963-1989.

Source: Southwick and Norman, Virginia Department of Game and Inland Fisheries, 1991

In summary, the existing information on fish populations in Back Bay suggests the following conclusions:

- The abundance and composition of fish populations in Back Bay have been irregularly monitored since 1951-52; since then, data have been collected in 1959-63, 1978-81, 1985-86, and in 1989.
- Despite declining populations of important recreational fish species, such as largemouth bass, the current fish community does not appear to be atypically depauperate when compared with the records since the 1950s. Richness of brackish species, as compared to freshwater species, was similar in 1989, however, three brackish species represented 60% of the total standing crop.
- Recruitment of young by freshwater populations will perhaps increase in the future as Back Bay is maintained at lower salinities (less than 3.5 part per thousand). However, the adult survival of fish species that are recreationally harvested may be jeopardized by low submerged aquatic vegetation abundance.

## Waterfowl

Back Bay National Wildlife Refuge staff and local hunting clubs, as well as anecdotal observations, indicate that Back Bay has been an important wintering area for waterfowl since at least the mid-1800s. Although this date coincides with the closing of the Currituck Inlet in 1830, and associated changes in the composition and abundance of the submerged aquatic vegetation in Back Bay, Sincock et al. (1965b) concluded that "it is not known with certainty whether waterfowl use of the area increased significantly after the closing of the Currituck Inlet." Chapell (1951; cited in Sincock et al. 1965) suggested that "it may be that the closing of the inlet just coincided with the beginning of waterfowl exploitation on the Atlantic Seaboard." It is important to note that duck shooting, for market and sport, was really just beginning in the East following the mid-1800's Civil War period (Dunbar 1956; cited in Sincock et al. 1965b). In Back Bay and Currituck Sound estuaries, market hunting for waterfowl became a leading occupation after the Civil War, and continued until 1918, when the Migratory Bird Treaty Act made the sale of migratory waterfowl illegal (Sincock et al. 1965b).

Prior to 1937, the best data were recorded as kill rates ( i.e., waterfowl killed per man-day) by local hunting clubs. Sincock et al. (1965b) summarized the records of ten major hunting clubs from 1872 - 1964 and graphed the data as 5-year averages to smooth irregularities (Figure 8). The graphed data shows that dabbling ducks comprised most of the total waterfowl abundance during this period, regardless of varying kill rates. Sincock et al. (1965b) used the same records to graph the waterfowl kill rates and data on man-days of hunting (Figure 9). Kill rates increased from 1872 to a high in 1900, which was sustained until 1925. The average annual kill during this high period was generally greater than 15.0 waterfowl per man-day, and as high as 25.2 waterfowl per man-day.

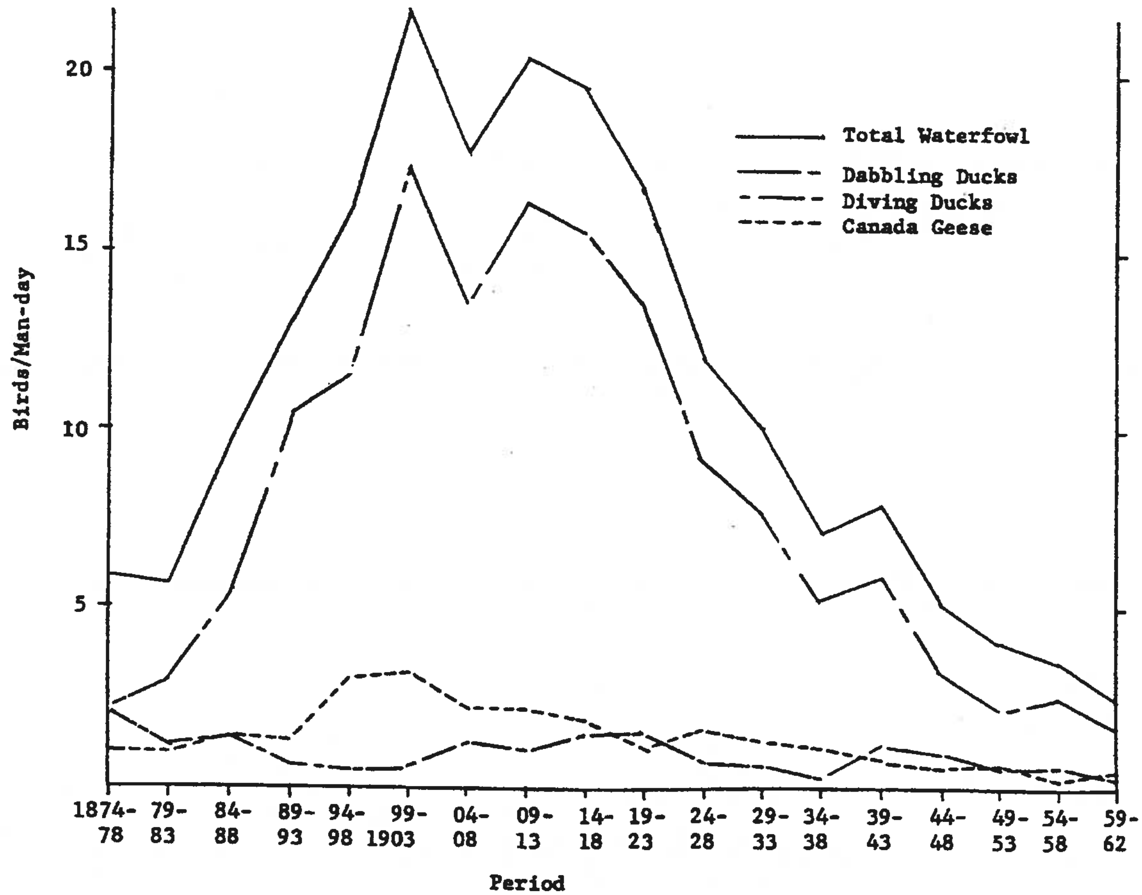


Figure 8. Average number of each waterfowl group per man-day of hunting by 5 year periods 1872-1962 from ten hunting club records on Back bay, Virginia and Currituck Sound, North Carolina.

Source: Sincock et al. in U.S. Dept. of Interior, Fish and Wildlife Service, 1965; Back Bay - Currituck Sound Data Report.


Figure 9. Man-days of hunting and average waterfowl kill per man-day by five year periods 1872-1962 from ten hunting club records on Back Bay, Virginia and Currituck Sound North Carolina.

Source: Sincock et al. in U.S. Dept. of Interior, Fish and Wildlife Service, 1965; Back Bay - Currituck Sound Data Report.

After 1927, the kill rate was consistently less than 10 waterfowl per man-day and continued to decrease to 1.64 waterfowl per man-day by 1962. Although Sincock et al. 1965b) acknowledged that these data are somewhat confounded by implementation of the Migratory Bird Treaty Act, and progressively more restrictive hunting regulations, hunter effort (man days) continued to increase after 1927, even as waterfowl kill rates declined.

The Mid-Winter Inventory (MWI) of Back Bay has been flown annually since 1937; though data are missing for 1941, 1946, 1948, 1952, and 1953 (Sincock et al. 1965b). The Back Bay survey unit of the MWI (Virginia Zone 4, Segment 14) extends from Dam Neck, west to U.S Route 17, south to the North Carolina State line, east along the State line to the Atlantic Ocean, then north to Dam Neck (Settle and Schwab 1991). The total waterfowl count was 9,925 in 1937 but increased to 363,050 by 1943, the highest MWI count recorded on Back Bay ever. Waterfowl kill rates were low in 1943, despite the record MWI count during that January. Either the kill rates of 1943 are not representative of the wintering waterfowl population that year (perhaps fewer hunters were out due to World War II activities), or populations were much higher at the turn of the century (reflected in high kill rates), than anytime since. MWI counts dropped to 20,500 in 1944, and again increased to about 90,000 by 1954 (Sincock et al. 1965). From 1954-90, MWI data were reviewed by Settle and Schwab (1991); correlation analyses suggest that wintering populations of dabbling ducks, diving ducks, geese, and tundra swans have declined since 1954, despite high annual variation. Total waterfowl counts have been less than 10,000 since 1982. In general, kill rates may primarily reflect an increasing denominator such as hunter effort, and variation in kill rates may be somewhat independent of waterfowl populations. Regardless of the uncertainty of waterfowl population levels prior to 1937, it is clear that current waterfowl use of Back Bay is low by historical standards.

Explanations for declining waterfowl use are conflicting. On one hand, Sincock et al. 1965) stated that "it is unfortunate that the local populace has always identified the drastic reduction in [waterfowl] use of the Back Bay-Currituck Sound area with the coincidental decline in the quality of that habitat." Sincock et al. cited several examples to disparage the association between submerged aquatic vegetation abundance and local waterfowl populations including: (1) Mid-winter inventories declined from 1,135,000 to 300,000 waterfowl during 1942-48, despite testimony by the manager of Back Bay National Wildlife Refuge that submerged aquatic vegetation abundance had improved during that same period; (2) waterfowl kill rates recorded by hunting clubs remained relatively constant during 1926-29, despite observations by Bourn that submerged aquatic vegetation distribution was further reduced during that same period; (3) local degradation of habitats should presumably result in similar variations among waterfowl populations; however, kill rates indicate that different species began to decline at different times: redheads in 1883, widgeon in 1898, mallards and Canada geese in 1903, teal in 1913, black duck, gadwall, and shoveler in 1918, and pintail and canvasback in 1923. These data suggest that at the turn of the century, conditions other than the environmental conditions of the wintering grounds at Back Bay, may have been instrumental in reducing waterfowl populations.

On the other hand, Sincock et al. 1965) also pointed out that variability in population levels is confounded by local food conditions, submerged aquatic vegetation, and human-induced disturbance levels (*e.g.*, hunting and boating activity). Settle and Schwab (1991) present circumstantial evidence that at least since 1958, winter waterfowl use and autumn submerged aquatic vegetation abundance are related (Figure 3). Waterfowl counts generally reflected the increases in submerged aquatic vegetation abundance prior to the 1962 "Ash Wednesday Storm" and during the 1970s' watermilfoil invasion.

Settle and Schwab (1991) also note that winter waterfowl use of Back Bay has declined as Atlantic Flyway and other Virginia populations of greater snow geese, Canada geese, and tundra swans have increased. Although Atlantic Flyway and Virginia populations of dabbling and diving ducks have declined, they have done so at much slower rates than those in Back Bay. These observations suggest that local conditions impact waterfowl use of Back Bay.

In summary, the existing information on waterfowl populations in Back Bay suggests the following conclusions:

- Waterfowl populations have been indexed almost continuously since 1872. Recorded kill rates of ten hunting clubs are available from 1872 - 1964. Except for five years, Mid-Winter Inventory data are available since 1937.
- Wintering populations of all major waterfowl groups in Back Bay have declined since 1954, and probably since the 1920s. Recent MWI counts are as low or lower than at anytime since 1937.
- Factors contributing to the decline of waterfowl populations are somewhat confounding. Long-term temporal changes in waterfowl abundance may be caused by factors outside the wintering grounds, and may be exacerbated at current levels of exploitation on the wintering grounds. Local food abundance and human disturbance likely influence waterfowl use of Back Bay. Since 1954, there is evidence that the lack of food abundance, SAV, may be influencing waterfowl use of Back Bay.

## SUMMARY AND RECOMMENDATIONS

In summary, several trends have been observed over time in Back Bay. The salinity of Back Bay has fluctuated up and down between saline, slightly brackish, and a nearly freshwater environment. Anecdotally, Weiland (1897) noted productive oyster beds being replaced by submerged aquatic vegetation (SAV), freshwater fisheries and waterfowl use with the closing of Currituck inlet. There has been a general decline in SAV populations, although Back Bay National Wildlife Refuge (Refuge) notes that in 1993 SAV appears to be making a slow come back in some areas. The Refuge also notes that winter waterfowl counts are currently a mere fraction of the observed numbers reported for the early part of this century. Historic waterfowl use observations correspond with a general decline in SAV populations since the early part of this century. Anecdotal observations indicate that the fish population may have been more marine in the early part of the century. Over the last four decades, which have been well documented, the fish species diversity, though nearly 50% freshwater, shows brackish water species accounting for 60% of the standing crop. The formerly renowned citation size largemouth bass fishery has been reduced from 17% of the biomass in 1980 to 2% of the biomass in 1986. Change in salinity (increased salinity proving toxic to young bass) and a lack of submerged aquatic vegetation (food source) have been suggested as possible causes of the declining fishery. In the less saline environment, recruitment of young bass may be more successful than in the past.

Recent sampling indicates elevated levels of nutrients are present in some areas of Back Bay. Preliminary sampling indicates that the tributaries appear to be sources of nutrients. Further quantification of nutrients and sediments entering Back Bay from tributaries should be conducted. Sources of the nutrients in the tributaries need to be identified. As researchers continue to document the trends and investigate the causes of the changes in Back Bay resources and water quality, mitigation of activities which adversely affect the natural resources and water quality should be implemented. Nutrient and sediment loads are discharged into Back Bay from agricultural and residential areas directly and via the tributaries. Additional sources of nutrients to Back Bay come from failing septic systems, impervious surfaces which promote runoff, and ineffective storm water collection and treatment systems. Best Management Practices (BMPs) to address these nutrient problems would include: buffer zones, easements, more stringent soil requirements for septic systems, and better stormwater collection, detention and treatment. The ensuing improved water quality will allow for growth of submerged aquatic vegetation and, subsequently, provide improved habitat for waterfowl, fish, and other aquatic and terrestrial wildlife.

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